Complex Systems Modeling Laboratory

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Refereed academic journal

[i-lubash-107-032-01:2015] Ihor Lubashevsky Arkady Zgonnikov. Double-well dynamics of noise-driven control activation in human intermittent control: the case of stick balancing. *Cognitive processing*, 16(4):351–358, 2015.

When facing a task of balancing a dynamic system near an unstable equilibrium, humans often adopt intermittent control strategy: instead of continuously controlling the system, they repeatedly switch the control on and off. Paradigmatic example of such a task is stick balancing. Despite the simplicity of the task itself, the complexity of human intermittent control dynamics in stick balancing still puzzles researchers in motor control. Here we attempt to model one of the key mechanisms of human intermittent control, control activation, using as an example the task of overdamped stick balancing. In so doing, we focus on the concept of noise-driven activation, a more general alternative to the conventional threshold-driven activation. We describe control activation as a random walk in an energy potential, which changes in response to the state of the controlled system. By way of numerical simulations, we show that the developed model captures the core properties of human control activation observed previously in the experiments on overdamped stick balancing. Our results demonstrate that the double-well potential model provides tractable mathematical description of human control activation at least in the considered task, and suggest that the adopted approach can potentially aid in understanding human intermittent control in more complex processes.

Refereed proceedings of an academic conference

[i-lubash-107-032-02:2015] Marie Watanabe Ihor Lubashevsky. Statistical Properties of Gray Color Categorization: Asymptotics of Psychometric Function. In *Proceedings of the 2015 ISCIE International Symposium on Stochastic Systems*, pages 140–149. University of Aizu, 2016.

The results of our experiments on categorical perception of different shades of gray are reported. A special color generator was created for conducting the experiments on categorizing a random sequence of colors into two classes, light-gray and dark-gray. The collected data are analyzed based on constructing (i) the asymptotics of the corresponding psychometric functions and (ii) the mean decision time in categorizing a given shade of gray depending on the shade brightness (shade number). Conclusions about plausible mechanisms governing categorical perception, at least for the analyzed system, are drawn.

[i-lubash-107-032-03:2015] Ihor Lubashevsky Takashi Suzuki Arkady Zgonnikov, Shigeru Kanemoto. How the Type of Visual Feedback Affects Actions of Human operators: The Case of Virtual Stick Balancing. In *Systems, Man, and Cybernetics (SMC), 2015 IEEE International Conference on*, pages 1100–1103. IEEE, 2015.

Maintaining vertical position of an inverted pendulum is a simple balancing task, which is widely used to study human control behavior. Yet, much about this behavior remains poorly understood even in the context of simple virtual tasks. The purpose of this study was to investigate whether the control behavior of human operators depends on the type of visual feedback from the controlled system. We analyze the experimental data on human stick balancing on a computer screen. The previous studies reported detailed analysis of the task performance of human operators observing only the angular deviation of the stick from the vertical. In this study we augmented the information supplied to the operator by linear displacement of the upper tip of the stick from the reference point. This additional information was suggested to improve the performance of the operators. Surprisingly, the subjects not only exhibited better performance, but also supposedly employed structurally different control mechanisms in the linear displacement condition. The found results may have potential implications both for fundamental research aimed at investigating the basic properties of human control, and applied research on human factors.

[i-lubash-107-032-04:2015] I. Lubashevsky A. Zgonnikov H. Ando, R. Yamauchi. Intermittent Control Properties of Car Following: I. Driving Simulator Experiments. In Vitaly Klyuev Evgeny Pyshkin, editor, *Proceedings of the International Workshop on Applications in Information Technology*, pages 8–9. University of Aizu, 2015.

A rather simple car driving simulator was created based on the available open source engine TORCS and used to analyze the basic features of human behavior in car driving within the car-following and free-driving setups. Four drivers with different skill in driving real cars participated in these experiments. They were instructed to driver a virtual car without overtaking the lead car driven by computer at a fixed speed and not to lose sight of it as well as to drive a virtual car on empty road in a style convenient individually. Based on the collected data the distribution of the headway, velocity, acceleration, and jerk are constructed and compared with available experimental data collected previously by the analysis of the real traffic flow. As the main results we draw a conclusion that the human behavior in car driving should be categorized as a generalized intermittent control with noise-driven activation of the active phase. Besides, we hypothesize that the car jerk is an individual phase variable required for describing car dynamics.

[i-lubash-107-032-05:2015] Ihor Lubashevsky Arkady Zgonnikov Ryoji Yamauchi, Hiromasa Ando. Intermittent Control Properties of Car Following: II. Dynamical Trap Model. In Vitaly Klyuev Evgeny Pyshkin, editor, *Proceedings of the International Workshop on Applications in Information Technology*, pages 10–12. University of Aizu, 2015.

A new model for car-following is proposed to capture the found properties in our previous experiments. It is based on the experimental results showing that (i) human behavior in car driving should be categorized as a generalized intermittent control with noise-driven activation of the active phase and (ii) the extended phase space required for model- ing human actions in car driving has to comprise four phase variables, namely, the headway distance, the velocity of car, its acceleration, and the car jerk, i.e., the time derivative of the car acceleration.

[i-lubash-107-032-06:2015] Alexander Vazhenin Kosuke Hijikata, Ihor Lubashevsky. Is the Modern Theory of Stochastic Processes Complete? Example of Markovian Random Walks with Constant Non-Symmetric Diffusion Coefficients. In Vitaly Klyuev Evgeny Pyshkin, editor, *Proceedings of the International Workshop on Applications in Information Technology*, pages 39–40. University of Aizu, 2015.

A new type non-symmetric diffusion problem is considered and the corresponding Brownian motion implementing such diffusion processes is constructed. As a particular example, random walks with internal causality on a square lattice are studied in detail. By construction, one elementary step of a random walker on the lattice may consist of its two succeeding jumps to the nearest neighboring nodes along the x- and then y-axis or the y- and then x-axis ordered, e.g., clock-wise. caused by the first one, meaning that the second fragment can arise only if the first one has been implemented, but not vice versa. for some reasons the second fragment is blocked, the first one may be not affected, whereas if the first fragment is blocked, the second one cannot be implemented in any case. the duration of one elementary step these random walks are characterized by a diffusion matrix with non-zero anti-symmetric component. The existence of this anti-symmetric component is also justified by numerical simulation.

[i-lubash-107-032-07:2015] Alexander Vazhenin Kosuke Hijikata, Ihor Lubashevsky. Is the Modern Theory of Stochastic Processes Complete? Example of Markovian Random Walks with Constant Non-Symmetric Diffusion Coefficients. In Vitaly Klyuev Evgeny Pyshkin, editor, *Proceedings of the International Workshop on Applications in Information Technology*, pages 39–40. University of Aizu, 2015.

A new type non-symmetric diffusion problem is considered and the corresponding Brownian motion implementing such diffusion processes is constructed. As a particular example, random walks with internal causality on a square lattice are studied in detail. By construction, one elementary step of a random walker on the lattice may consist of its two succeeding jumps to the nearest neighboring nodes along the x- and then y-axis or the y- and then x-axis ordered, e.g., clock-wise. It is essential that the second fragment of elementary step is caused by the first one, meaning that the second fragment can arise only if the first one has been implemented, but not vice versa. In particular, if for some reasons the second fragment is blocked, the first one may be not affected, whereas if the first fragment is blocked, the second one cannot be implemented in any case. As demonstrated, on time scales much larger then the duration of one elementary step these random walks are characterized by a diffusion matrix with non-zero anti-symmetric component. The existence of this anti-symmetric component is also justified by numerical simulation.

[i-lubash-107-032-08:2015] Ihor Lubashevsky Marie Watanabe, Ren Namae. Asymptotics of Psychometric Function of Gray Color Categorization. In Vitaly Klyuev Evgeny Pyshkin, editor, *Proceedings of the International Workshop on Applications in Information Technology*, pages 41–42. University of Aizu, 2015.

The results of conducted experiments on categorical perception of different shades of gray are reported. A special color generator was created for conducting the experiments on categorizing a random sequence of colors into two classes, light-gray and dark-gray. The collected data are analyzed based on constructing (i) the asymptotics of the corresponding psychometric functions and (ii) the mean decision time in categorizing a given shade of gray depending on the shade brightness (shade number). Conclusions about plausible mechanisms governing categorical perception, at least for the analyzed system, are drawn.

[i-lubash-107-032-09:2015] Shigeru Kanemoto Ihor Lubashevsky Takashi Suzuki, Arkady Zgonnikov. Effect of Extended Visual Feedback on Human Information Processing in Virtual Stick Balancing. In Vitaly Klyuev

Evgeny Pyshkin, editor, *Proceedings of the International Workshop on Applications in Information Technology*, pages 35–38. University of Aizu, 2015.

The results of our experiments aimed at estimating the distribution of the response delay time in human intermittent control over unstable mechanical systems are presented. A novel experimental paradigm: balancing an overdamped inverted pendulum was used. The created simulator of balancing a virtual pendulum makes the pendulum invisible when the angle between it and the upward position is less than 5o, which enabled us to measure directly the delay time. It is demonstrated, in particular, that (i) the response delay time may be treated as a random variable distributed within a wide interval and (ii) the response delay in human intermittent control may be determined by cumulative actions of two distinct mechanisms, automatic and international, endowing it with complex nonlinear properties.

[i-lubash-107-032-10:2015] Shigeru Kanemoto Ihor Lubashevsky Takashi Suzuki, Arkady Zgonnikov. Effect of Extended Visual Feedback on Human Information Processing in Virtual Stick Balancing. In Vitaly Klyuev Evgeny Pyshkin, editor, *Proceedings of the International Workshop on Applications in Information Technology*, pages 35–38. University of Aizu, 2015.

Maintaining vertical position of an inverted pendulum is a simple balancing task, which is widely used to study human control behavior. Yet, much about this behavior re- mains poorly understood even in the context of simple virtual tasks. The purpose of this study was to investigate whether the control behavior of human operators depends on the type of visual feedback from the controlled system. We analyze the experimental data on human stick balancing on a computer screen. The previous studies reported detailed analysis of the task performance of human operators observing only the angular deviation of the stick from the vertical. In this study we augmented the information supplied to the operator by linear displacement of the upper tip of the stick from the reference point. This additional information was suggested to improve the performance of the operators. Surprisingly, the subjects not only exhibited better performance, but also supposedly employed structurally different control mechanisms in the linear displacement condition. The found results may have potential implications both for fundamental research aimed at investigating the basic properties of human control, and applied research on human factors.

Writing a part of textbook or technical book

[i-lubash-107-032-11:2015] Ihor Lubashevsky. *Handbook of Applications of Chaos Theory*, chapter Human Fuzzy Rationality as a Novel Mechanism of Emergent Phenomena, pages 827–877. Chapman and Hall/CRC, 2016.

The chapter is divoted to a new emergence mechanism related to the human fuzzy rationality. It assumes that individuals (operators) governing the dynamics of a certain system try to follow an optimal strategy in controlling its motion but fail to do this perfectly because similar strategies are indistinguishable for them. The main attention is focused on the systems where the optimal dynamics implies the stability of a certain equilibrium point in the corresponding phase space. In such systems the fuzzy rationality gives rise to some neighborhood of the equilibrium point, the region of dynamical traps, wherein each point is regarded as an equilibrium one by the operators. So, when the system enters this region and while it is located in it, maybe for a long time, the operator control is suspended. To elucidate a question as to whether the dynamical traps on their own can cause emergent phenomena, the stochastic factors are eliminated from consideration. In this case the system can leave the dynamical trap region only because of the mismatch between actions of different operators. By way of example, a chain of oscillators with dynamical traps is analyzed numerically. As demonstrated, the dynamical traps do induce instability and complex behavior of such systems.

Advisor for undergraduate research and graduate research

[i-lubash-107-032-12:2015] Hiromasa Ando. Intermittent Control Properties of Car Following: Theory and Driving Simulator Experiments, Graduate School, 2016.

A rather simple car driving simulator was created based on the available open source engine TORCS and used to analyze the basic features of human behavior in car driving within the car-following setups. Eight subjects with different skill in driving real cars participated in these experiments. They were instructed to drive a virtual car without overtaking the lead car driven by computer at a fixed speed and not to lose sight of it. Moreover, these experiments were conducted with four different speed including 60km/h, 80km/h, 100km/h, and 120km/h. Based on the collected data the distribution of the headway, velocity, acceleration, and jerk are constructed and compared with available experimental data collected previously by the analysis of the real traffic flow. A new model for car-following is proposed capture the found properties. As the main results we draw a conclusion that the human behavior in car driving should be categorized as a generalized intermittent control with noise-driven activation of the active phase. Besides, we hypothesize that the extended phase space required for modeling human actions in car driving has to comprise four phase variables, namely, the headway distance, the velocity of car, its acceleration, and the car jerk, i.e., the time derivative of the car acceleration. This time, the time pattern of pedal pushing and the distribution of time derivative of pedal was utilized in addition to previous variables. Moreover, all subjects driving data were categorized as some styles with their shapes.

[i-lubash-107-032-13:2015] Ryoji Yamauchi. Styles of the car-driving as human intermittent control: Experiments with car-driving simulator, Undergraduate School, 2016.

A rather simple car-driving simulator was created based on the available open source engine TORCS and used to analyze the basic features of human behavior in car-driving within the car-following setup. Eight subjects with different skill in driving real cars participated in these experiments. They were instructed to drive a virtual car without overtaking the lead car driven by computer at a fixed speed and not to lose sight of it. In four setups of experiments involved each participant the lead car speed took different values from 60 km/h up to 120 km/h. Previously we have demonstrated that the car-driving should be catego- rized as a generalized intermittent control with noise-driven activation. The goal of the present work is to single out the characteristic types of driver actions called car-driving styles. For this purpose the data of the car pedal position, which directly reflects subject's actions, were analyzed. Five different car-driving styles have been detected within the conducted experiments.